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Geologic application of thermal-inertia mapping from satellite

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A. Problems

No HCCM CCTs have been received during this reporting period. The black and white prints have been of poor quality for the daytime thermal and visible data. This latter problem has been brought to NASA's attention.

B. Accomplishments

The USGS scanner acquired data last October on an east/west line of latitude 43°27' in Wyoming. The swath width of the line was approximately 4.25 miles. Data from a portion of this line--from 105°21' to 105°29'--were digitized, and a noise rejection filter was applied. An albedo image was formed by combining three bands of visible data. This was the first attempt at creating an albedo image in this manner, and the resulting product appears constant with ground measurements. The albedo image along with the day and nighttime thermal data was used to construct a relative thermal-inertia image. This image, registered to a topographic base, shows there are thermal property differences in the vicinity of the contact between the Fort Union and Wasatch Formations. The next segment of flight line just west of the thermal-inertia image will be processed and concatenated before further evaluation can be made. The thermal-inertia image will be analyzed to see if thermal property differences can be used to distinguish the two geologic formations. This thermal-inertia image will also be compared to a satellite thermal-inertia map as appropriate data are made available.

Another set of data was processed from the October Wyoming mission. The longitude of the flight line is 106°57'30", and the portion from 44°54' to 44°57' latitude was processed. An algorithm for geothermal heat-flux mapping was applied to these data to the underground coal fires known to be present in the area. The resulting heat-flux map showed significant topographic heating effects as well as the coal fire areas. The topographic problem will require further investigation.

C. Significant Results

The significant results from this report period are: constructed a topographically registered relative thermal-inertia image of a portion of the Powder River Basin, Wyoming, using USGS aircraft data.

For further details, see the accomplishment section.

D. Publications and Presentations

Ken Watson was an invited speaker at the Thirteenth International Symposium on Remote Sensing of the Environment held April 23 at the University of Michigan. The title of his talk was "Regional thermal-inertia mapping to discriminate geologic materials". A copy of the summary is submitted with this report. Susanne Miller presented a poster session titled"The use of thermal data to extend geologic reconnaissance from satellites" at the symposium.

E. Recommendations

We need satellite data to complete this contract.

F. Funds Expended

Total expenditures to date: \$71,328

G. Data Utility

About 70 black and white screening prints have been received. Of these, there is one day/night set of the Powder River Basin that looks promising. The day thermal and visible prints are washed out so the quality of the data cannot be determined. The CCTs of these data have been ordered.

REGIONAL THERMAL-INERTIA MAPPING TO DISCRIMINATE GEOLOGIC MATERIALS

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SUMMARY

The launch of the HCMM satellite in April 1978 introduced a new era in geologic exploration by satellite. For the first time, thermal data appropriate for reconnaissance use and available over large regions of the globe are being acquired. Prior to this time, the primary sources of thermal data were either from aircraft or from weather satellites. Aircraft data are very restricted in geographic coverage, and of limited availability and accessibility to the scientific community. Meteorological satellite data have been acquired at too low a spatial and thermal resolution or at inappropriate times for most regional geologic applications.

Thermal-infrared data provide unique geologic information, complementing that obtained from Landsat reflectance data. Thermal inertia, a property derived from measurements of the surface-temperature response of materials to a known heating flux, is dependent on the density, the water content, and the composition of geologic materials. Thus it provides an additional dimension by which to discriminate units by remote sensing means. Also, because this property is derived from measurements over the diurnal cycle, its value is a weighted average over the thermal skin depth, thus providing information beneath that surface which is sensed by reflectance measurements. This skin depth varies between about 5 and 15 cm for materials ranging from dry soil to outcrop.

Thermal inertia of geologic materials correlates in a roughly linear fashion with bulk density; however, notable exceptions exist. For example, rocks high in quartz content have high thermal inertias; dolomites generally have thermal inertias roughly twice those of limestones; most igneous rocks have thermal inertias very similar to each other, and the moisture content of soils has a very significant effect on thermal inertia (an 8% increase in moisture of sandy soil results in a 6% density increase and a 75% thermal inertia increase). Thermal property measurements can thus be used to discriminate certain lithologic types, to map alteration associated with silicification or dolomitization, to differentiate soils with varying moisture contents and porosities, and to discriminate geologic units which are obscured by the presence of surface cover such as thin soil or desert varnish.

As with Landsat data, optimal usage of thermal data requires digital processing. However, two additional factors make the analysis more complex. The first is that the surface temperature is dependent not only on the incident solar flux but also on other fluxes such as the downward-sky thermal radiation and the atmospheric convective heat transfer--the latter two of which are not observable from satellites. The second factor is that the surface temperature is a response to the previous history of the surface fluxes--unlike reflectivity measurements which are instantaneous values independent of the previous fluxes. Accounting for these two factors requires three additional constraints for the optimal extraction of geologic information from thermal data: (a) collection of repetitive thermal data, (b) development of a thermal model, and (c) availability of regional meteorologic information.

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Day and night thermal data can be used to estimate the amplitude of the diurnal surface-temperature variation, and daytime reflection data can be used to compute the absorbed solar flux. These data can then be mathematically combined to obtain an estimate of the thermal inertia. A quantity defined as (1-A)/DV, where A is the reflectivity and DV is the day-night temperature difference, is called the relative thermal inertia. Under clear, stable meteorological conditions, and in areas of slight topographic relief and vegetation cover, this quantity has been related to the thermal inertia of the geologic materials using a simple thermal model. Various parametric forms relating this relative value to actual thermal inertia have been developed, and our current research indicates that a non-linear relationship is required. The use of a linear and proportional law can be satisfactory in certain cases where large thermal-inertia differences exist. The additional complexity introduced by topographic relief, vegetation cover, and convective heat transfer have only been considered in rudimentary form. Regional meteorological variations introduce an ultimate constraint on the applicability of the technique; because the critical data necessary to account for these effects are rarely collected in a routine fashion over many areas. The most promising initial use of thermal-inertia mapping will thus be limited to those data sets acquired during nearly optimum meteorological conditions.

Thermal data provide information in addition to thermal property values for geologic studies. Unique enhancements of topographic features have been previously reported, including display of various types of geomorphic information at different scales, depending on the time of day. Subtle, structurally controlled moisture zones have been detected on thermal images, and detection of geothermal heat fluxes ranging from effusive volcanism and hot springs to features with no visible anomaly has been reported.

Further extensions of the use of thermal data for geologic studies will be based on the development of more complete thermal models, the routine use of topographic and regional meteorological data in the analysis, and incorporation of satellite data acquired at additional times in the diurnal cycle. These studies should ultimately lay the ground work for the development of future thermal satellite systems with similar crossing times and thermal characteristics but with higher ground resolution (comparable to the present Landsat system) and truly worldwide data coverage.